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Evaluation of Air Pollution Abatement Systems for Multiple-Hearth Sewage Sludge Incinerators

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Evaluation of Air Pollution Abatement Systems for Multiple-Hearth Sewage Sludge Incinerators

by

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16. ABSTRACT

Capital and annual costs were calculated for the application of six different air pollution control system options to municipal sewage sludge incinerators that were using multiple-hearth furnaces. The systems involved three principal types of air pollution equipment--wet scrubbers, fabric filters, and electrostatic precipitators--applied to three different plant sizes (plants incinerating 36, 72, and 300 tons of dry sludge per day in one, two, and eight multiple-hearth furnaces, respectively). The six options were: (1) venturi/tray scrubber with a 40-inch pressure drop, (2) fabric filter system operating at 500°F and equipped with an upstream temperature control, (3) fabric filter system operating at 500°F and equipped with a heat exchanger and a scrubber for SO_2 reduction, (4) electrostatic precipitator (ESP) with upstream limited temperature and humidity control, (5) same as Option 4 but with an additional downstream wet scrubber for SO_2 reduction, and (6) ESP with upstream temperature control and an SO_2 scrubber.

Technical feasibility studies indicated that all three types of controls could achieve a total particulate removal efficiency of 99 percent. The venturi/tray scrubber option entailed the lowest capital cost, but annual operating costs were highest because of the high pressure drops and increased energy use.

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EVALUATION OF AIR POLLUTION ABATEMENT SYSTEMS FOR MULTIPLE-HEARTH SEWAGE SLUDGE INCINERATORS

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SUMMARY

Capital and annualized costs have been calculated for the application of six different air pollution control systems involving three principal types of air pollution control equipment (wet scrubbers, fabric filters, and electrostatic precipitators) on municipal sewage sludge incinerators where multiple hearth furnaces are used. The costs were evaluated for three different plant sizes (incinerating 36, 72, and 300 tons of dry sludge per day in one, two, and eight multiple-hearth furnaces, respectively). The following six options were investigated:

1) Venturi/tray scrubber with a 40-in. pressure drop.

2) A fabric filter system operating at 500°F and equipped with an upstream temperature control.

3) A fabric filter system operating at 500°F and equipped with a heat exchanger and a scrubber for SO_2 reduction.

4) An electrostatic precipitator (ESP) with upstream limited temperature and humidity control.

5) Same as option 4 but with an additional downstream wet scrubber for SO_2 reduction.

6) An ESP with upstream temperature control and an SO_2 scrubber.

An induced-draft (I.D.) fan in the incinerator system primarily maintains the draft in the incinerator and provides the power to overcome the pressure drop in the air pollution control system. Because the I.D. fan controls combustion in the incinerator, a single air pollution control system cannot be used for more than one incinerator. Because of this operational limitation, each incinerator is provided with its own captive air pollution control system.

Table I presents capital and annualized costs for the six options and three plant sizes. Technical feasibility studies indicated that all three types of controls could achieve a total particulate removal efficiency of 99 percent. The venturi/tray scrubber option has the lowest capital costs of the six options. The annualized costs of this option are high, however, as a result of the high pressure drops and increased energy use. Most U.S. municipal sewage sludge incinerators with multiple-hearth furnaces use wet scrubbers to control air pollution emissions. None of them use fabric filters or ESP's. In Japan, ESP's are used for this application.

The predominant use of wet scrubbers for air pollution control may be due to the ample supply of water, readily accessible wastewater treatment facilities, and waste disposal facilities. Other factors are reduced odor problems and the operating experience already gained.

None of the U.S. plants have SO_2 scrubbers installed for this application. Emissions of SO_2 are generally low, contributed primarily by supplemental fuel burned at the incinerator. The SO_2 scrubbing requirements should be determined on a case-by-case basis; they are presented here for illustrative purposes.

FEASIBILITY EVALUATION OF CONTROL OPTIONS

Several types of particulate removal devices can be used on sewage sludge incinerators where multiple-hearth furnaces are used. Three types are evaluated in this report: 1) wet scrubbers, 2) fabric filters, and 3) electrostatic precipitators.

The following factors must be considered in judging the practical applicability of an emission control system for sludge incinerators:

- High degree of particulate removal required (99 percent in this study).
- Presence of condensible fumes, which requires that gases be cooled as much as practical.
- Temperature of the gas entering the control equipment.
- High inlet particulate loading.
- High moisture content of the gas.
- Presence of acid gases (such as chlorides).

Wet Scrubbers

In the United States, wet scrubbers (generally venturi or impingement type) have traditionally been used to control particulate emissions from multiple-hearth incinerators. Best available control technology (BACT) for sludge incineration calls for the use of venturi type scrubbers operating at a minimum pressure drop of about 15 in. H_2O. These scrubbers are widely used

Table I. Capital and annualized costs for plants[a] with one, two, and eight multiple-hearth furnaces[a].
(thousands of mid-1985 dollars)

Plant size, 10^6 gal/day	Number of incinerators	Option 1--venturi/tray scrubbers		Option 2--fabric filter		Option 3--fabric filter and SO_2 scrubber		Option 4--electrostatic precipitator (ESP)		Option 5--ESP followed by SO_2 scrubber		Option 6--ESP preceded by SO_2 scrubber	
		Capital costs	Annualized costs	Capital costs	Annualized costs	Capital costs	Annualized costs	Capital costs	Annualized costs	Capital costs	Annualized costs	Capital costs	Annualized costs
36	1	$1,007	$ 595	$1,484	$ 418	$ 2,062	$ 547	$ 1,850	$ 404	$ 2,055	$ 484	$ 2,112	$ 493
72	2	1,757	1,141	2,598	781	3,613	1,018	3,243	740	3,601	881	3,701	895
300	8	6,448	4,452	9,531	2,463	13,247	3,895	12,074	2,828	13,408	3,375	13,781	3,430

[a] Options 3, 5, and 6 have an additional scrubber for SO_2 control. Gas flow from each incinerator is 19,053 scfm or 94,469 acfm at 1142°F. Average moisture content is 39.12 percent. Annualized costs are calculated on the basis of 10 percent interest rate and a useful life of 10, 20, and 20 years for venturi scrubbers, fabric filters, and electrostatic precipitators, respectively.

to achieve compliance with existing regulations and New Source Performance Standards.[1] The key parameters affecting the efficiency of wet scrubbers are particle size distribution and gas velocity through the scrubber.

The advantages and disadvantages of the use of conventional wet scrubbers in this application are summarized below:

Advantages	Disadvantages
° Cools gas to approximately 120°F and condenses volatile matter.	° Power requirements are high for collection of submicrometer size fume.
° Collected particulate is handled in wet form.	° Has low efficiency for fume or particles of submicrometer size.
° Application at many incinerators has achieved compliance with strict emission standards.	
° Removes acid gases and other soluble materials.	
° Reduces odor problems.	

According to Federal EPA source test data, SO_2 emissions from sludge incinerators amount to approximately 0.8 lb/ton of dry sludge after the gases have passed through a wet scrubber for particulate control.[2] Stack gas concentrations ranging from 2 to 14 parts per million (ppm) of SO_2 by volume have been measured at other incinerators.[3] The use of fuel oil at most sludge incinerators contributes to SO_2 emissions.

Because of the low level of SO_2 emitted from sludge incinerators, no controls are utilized specifically for its control in the United States. Theoretically, the addition of a caustic reagent (e.g., lime or sodium hydroxide) to the particulate scrubber water would reduce SO_2 emissions. This approach has been used successfully on combustion sources where SO_2 concentrations generally range from 500 to 2000 ppm. In these applications, the higher SO_2 concentration provides a greater "driving force" to cause the SO_2 to dissolve in the solution and react with the caustic reagent. At the low concentrations found in sludge incineration exhaust gas, however, a very large contacting surface and contact time would be required to compensate for the low reaction driving force. In such cases, venturi scrubbers used for particulate control do not provide the required contact area or gas residence time for optimum high-efficiency gas absorption. Thus, an additional gas contactor such as a spray tower or mobile-bed scrubber would have to be added to the gas cleanup system to achieve an SO_2 removal efficiency of about 80 percent.

Fabric Filters

Fabric filters are used widely for particulate control, especially in the metallurgical industry (steel and ferroalloys), where hot gases and fine fumes are encountered. Properly designed and operated fabric filtration systems operate reliably and remove submicrometer size particles with a high level of efficiency. Impaction and impingement are the primary removal mechanisms for particles larger than 1 μm; diffusion and electrostatic forces attract the smaller particles.

If the gas were cooled to at least 500°F, a fabric filter system could be used at sludge incinerators. Cooling could be accomplished by water spray and/or air dilution. If gas were cooled to between 200° and 300°F, a smaller fabric filter system could be used; some moisture condensation may occur, however, especially along the cooler walls of the collector and during incinerator startup conditions. When gas is cooled below its dewpoint, particulates will "cake" on the fabric and eventually cause plugging. If the gas is only cooled to between 300° and 400°F to minimize condensation problems, highly volatile compounds may not be completely condensed and collected. Alternate arrangements for fabric filter system heating may be required during startup of the incinerator to prevent condensation. The trade-off between fabric filter system size and operational problems will have to be carefully evaluated. Intermittent operation of the incinerator also may create condensation problems in the fabric filter.

Fabric filters will not remove gases unless additives are added to the gas stream to effect adsorption on the filter cake.

Approximately 0.3 to 0.5 ft^2 of fabric would be required for each cubic foot/minute of exhaust gas (air-to-cloth ratio of 2 or 3 to 1), depending on the temperature. Pressure drop through the fabric filter system would be about 4 to 8 in. H_2O, depending on the cleaning cycle.

For high-temperature applications, bags made of Nomex (up to 425°F), Teflon (up to 450°F), or fiberglass (up to 550°F) are used.

The following is a summary of the advantages and disadvantages of the application of fabric filter systems to sludge incineration:

Advantages	Disadvantages
° High efficiency--even in submicrometer size range.	° Gas must be cooled to less than about 500°F, but not to less than about 250°F because of potential plugging problems.
° Medium pressure drop.	° Operation is very sensitive to gas temperature.
° Considerable operating experience has been gained on other industrial processes.	

- Filter cannot remove acid gases unless additives or coated fabrics are used.
- Sticky deposits may cause bag blinding.
- Systems are relatively large.
- Systems have never been used on sewage sludge incinerators.
- Collected particulate is dry and must be wetted prior to handling (this might be an advantage, depending on the ultimate disposal of this material).
- Does not remove odors.

Electrostatic Precipitators

High-voltage, single-stage precipitators have successfully collected both solid and liquid particulate matter from smelters, steel furnaces, power plants, petroleum refineries, cement kilns, acid plants, and many other operations. These devices have achieved high efficiencies on metallurgical processes where the mean particle diameter is less than 1 μm. Removal efficiency is lowest when particles are in the 0.2- to 0.4-μm range; however, the efficiency for smaller and larger particles increases rapidly.

Although precipitators can operate at almost any temperature within the unit's structural limitations, particle resistivity varies widely with temperature, and for many applications, reaches a maximum in the 250° to 350°F range. Lower resistivity is preferable for optimization of particle charging and increased migration velocity.

Electrostatic precipitators can be operated in the wet or dry mode; i.e., above or below the gas dewpoint. In the wet mode, the gas is quenched and the collecting plates are sprayed with water for continual washdown of any collected particulate. Operation in the wet mode decreases particle resistivity and allows operation at a lower gas temperature. Because the particles are wetted, collection efficiency is much less dependent on dry particle resistivity. The wet mode also provides for absorption of acid gases and soluble material and prevents particle reentrainment. Wet ESP's have been applied widely to metallurgical processes, acid mist collection, coke oven gas purification, and other processes where wet conditions either prevail or are desired. Because the water continuously cleans the collecting plates, the electrical field strength between the discharge electrode and plate can be maintained at a high level, and no insulating effect occurs from

particulate buildup. Because no plate cleaning is necessary, there is no reentrainment of collected particulate such as that which occurs in dry ESP's when the plates are rapped to dislodge particulate matter.

The following is a summary of the advantages and disadvantages of dry electrostatic precipitators:

Advantages	Disadvantages
° Can operate at high temperature.	° Higher penetration in the range of 0.2- to 0.4-μm size.
° Low pressure drop.	° These systems have never been used on sewage sludge incinerators in the United States.
° Considerable operating experience has been gained in other industrial processes.	° Possible corrosion problems due to presence of acid gases.
° Low power consumption	° Collected particulate is dry and must be wetted prior to handling (this may be an advantage, depending on ultimate disposal of this material).
	° Does not remove odors.
	° Specially trained maintenance personnel are required to maintain high-voltage electrical equipment.

The following is a summary of the advantages and disadvantages of wet electrostatic precipitators:

Advantages	Disadvantages
° High efficiency for small particles.	° These systems have never been used on average sludge incinerators.
° Low pressure drop.	° Relatively large size.
° Low power consumption.	° Possible corrosion problems.

- Removes acid gases and soluble materials.
- Cools gas and condenses volatile matter.
- Controls acidic mists.
- Reduces odor problems.
- Specially trained maintenance personnel required to maintain high-voltage electrical equipment.

Discussions with experts in the incinerator design and operations field[4,5,6] confirmed that fabric filters and ESP's can be used for particulate emission control in sewage sludge incinerators where multiple-hearth furnaces are used.

SELECTION OF APPLICABLE CONTROL SYSTEMS AND ANCILLARY EQUIPMENT

Three types of primary particulate removal devices were evaluated for possible application on multiple-hearth furnace sewage sludge incinerators.

Evaluation Bases

Design Operating Data.

The evaluation was based on the following design operating conditions at the incinerators.

Gas exhaust conditions:

Temperature	616.8°C (1142°F)
Gas flow	8.99 Nm^3/s (19,053 scfm)
	44.58 m^3/s (94,469 acfm)
Moisture	39.12 percent by volume
Particulate concentration	1.774 gr/scf
Emission rate	289.7 lb/h

Size distribution of the inlet particulates:

Size fraction, μm	Wt. percent
0.1 to <1.0	10
1.0 to 3.5	12
3.5 to 10	9
>10	69

Other Pertinent Data.

Other data on which the estimates are based are as follows:

Incinerator exhaust gas composition:	
Carbon dioxide	10.3%
Oxygen	8.0%
Carbon monoxide	0%
Excess air	59%
Average stack velocity	10.12 mps (2000 ft/min)
Stack pressure, absolute	764 mm Hg
Design particulate control efficiency	99%+

Control Options

Capital and annualized costs for each selected option were developed for three plant sizes. The details of the plant sizes are as follows:

Number of incinerators	1	2	8
Sludge incineration, dry tons/day	36	72	300

The air pollution control system selected and the number and size of such units are dictated by the incineration process requirements. When multiple-hearth furnaces are used, an induced-draft (I.D.) fan is an integral part of the incinerator system; it controls and maintains the required negative pressure in the furnace and thus controls the incineration process. Hence, it is preferable that each incinerator have its own captive air pollution control system with the same I.D. fan providing the required pressure drop for the control equipment. Cost calculations are thus based on separate air pollution devices for each incinerator.

The six control options evaluated are listed here, and line flow diagrams of each are presented in Figures 1 through 6:

Option 1. Venturi and tray scrubber system with 40-in pressure drop.

Option 2. Fabric filter system operating at 500°F and having upstream temperature control.

Option 3. Fabric filter system operating at 500°F along with a heat exchanger and a scrubber for SO_2 reduction.

Option 4. ESP with upstream limited temperature and humidity control.

Option 5. ESP with upstream limited temperature and humidity control and an additional wet scrubber for SO_2 control.

Option 6. ESP system with upstream temperature control and an SO_2 scrubber.

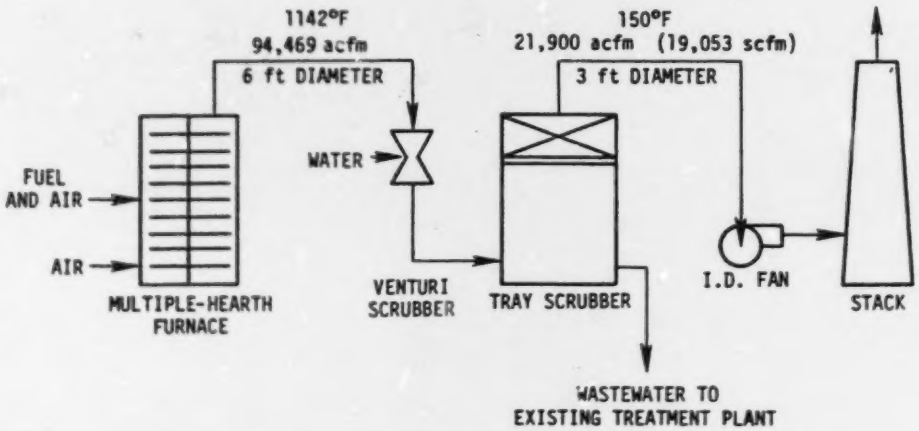

Figure 1. Option 1, venturi scrubber.

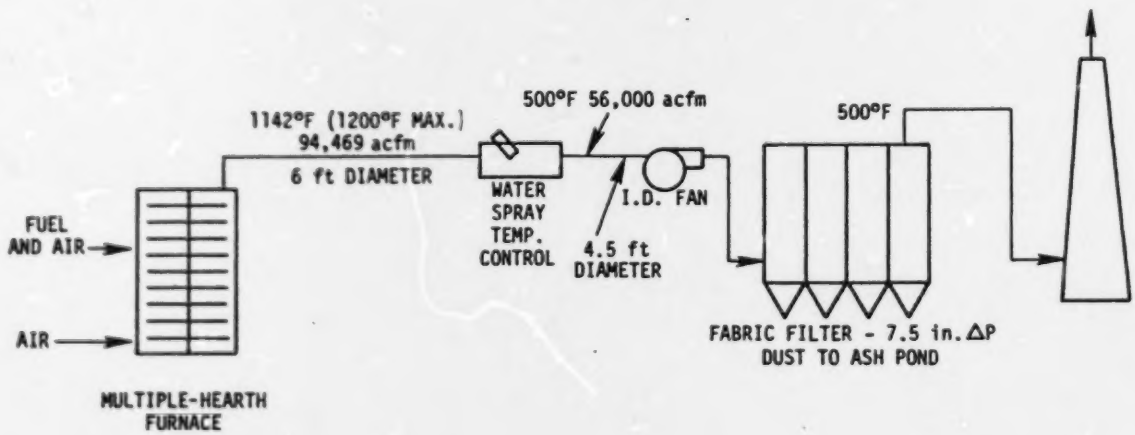

Figure 2. Option 2, fabric filter system.

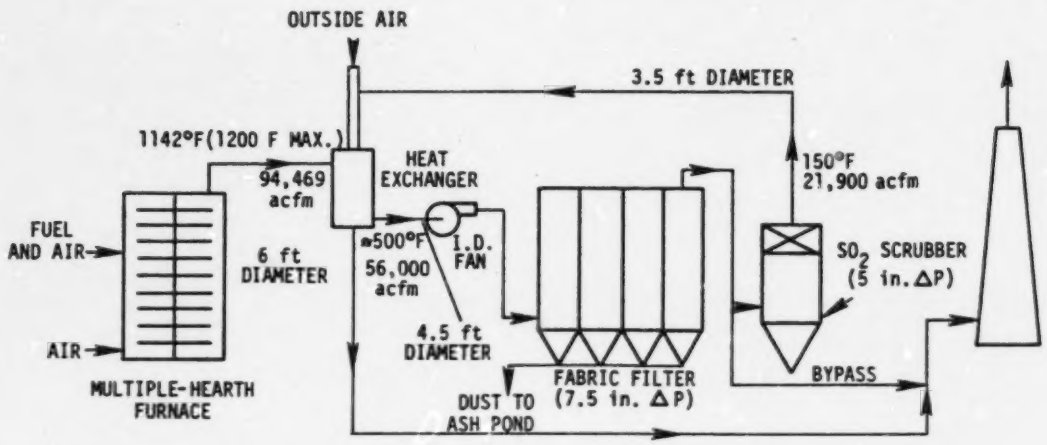

Figure 3. Option 3, fabric filter with a heat exchanger and SO_2 scrubber.

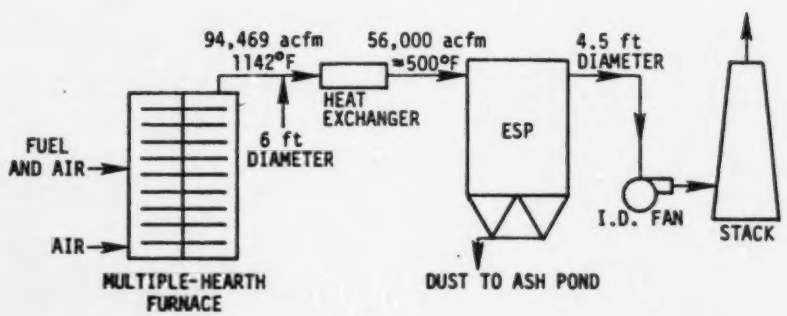

Figure 4. Option 4, electrostatic precipitator.

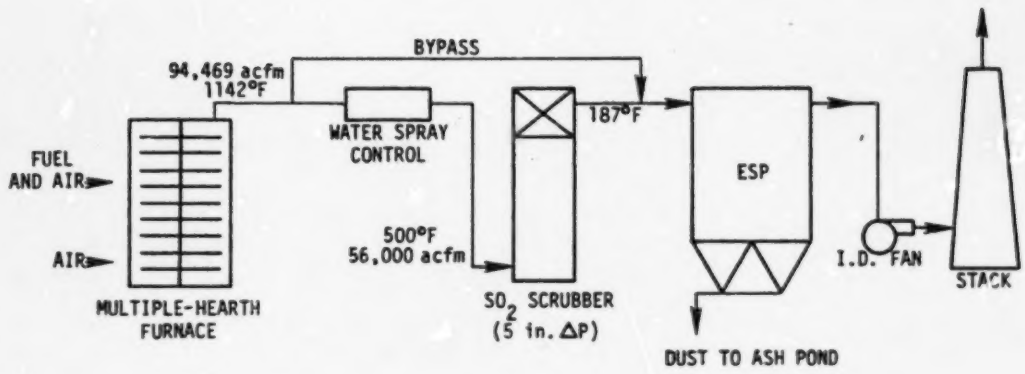

Figure 5. Option 5, ESP with downstream SO_2 scrubber.

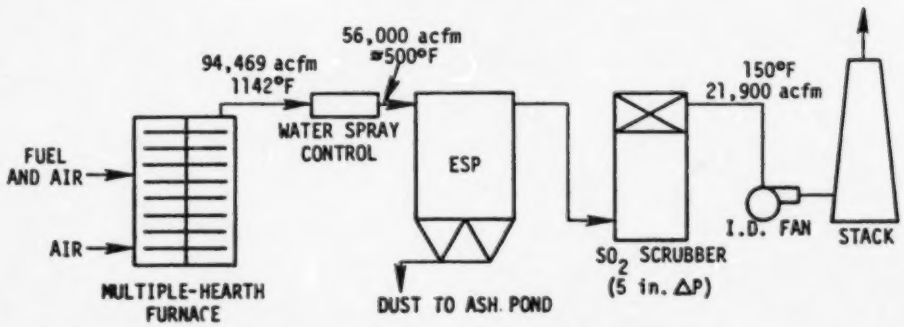

Figure 6. Option 6, ESP with upstream SO_2 scrubber.

Collection Efficiency Expected for Particulates in 0.1- to 1.0-μm Range

Design of air pollution control for a particular installation involves not only the selection of the appropriate type of device, but also the selection and sizing of the ductwork, dampers, and air-moving equipment. Sizing of ancillary equipment and the control device itself is largely a function of gas flow, particulate loading, and particle size distribution. Unfortunately, the particle size distribution is not known. Estimates can be based on measurements made at similar installations; however, these data are also very scarce and there is no certainty that the data are representative of any other installation. Size data are generally obtained by analysis of grab samples. The size distribution could vary whenever a change occurs in the waste quality (e.g., moisture content or heating value) and in the incinerator operating conditions. Hence, even the best of the past comparable data can be used only as a guide to estimate relative magnitudes of particulates in the off-gas. Determination of accurate size distribution unfortunately requires full-scale testing of actual equipment.[8]

No size-specific data are available for any of the three control options; however, medium-energy venturi scrubbers are believed to achieve 97 percent removal efficiency on 1-μm particles,[8] properly designed and operated fabric filter systems are said to achieve 99 percent removal efficiency on 1-μm particles,[8] and high-efficiency electrostatic precipitators can achieve 98 percent removal efficiency on 1-μm particles.[8]

The information obtained from vendors shows the following estimated removal efficiencies for the size fraction in the 0.1- to 1-μm range.

Control equipment efficiency, %		
Scrubber system	Fabric filters	ESP's
97-98	98-99	90-95

For particulates above 1-μm size, the control equipment efficiency will be higher.

COST ESTIMATES

The cost estimates for capital costs and annualized costs for the six options and three plant sizes are presented in Table I.

Several vendors were contacted for control equipment costs. The quotes received were budget-type estimates made on a flange-to-flange basis. Some of the auxiliary equipment cost was supplied by the vendors, some was based on information contained in References 9 and 10, and some came from in-house data. Basic equipment cost and auxiliary equipment costs were estimated for each option.

Calculations of annualized costs were based on the estimated use of operating labor, maintenance labor, operating and maintenance supplies, replacement parts, and utilities. The data for these items were obtained

from the vendors, and normal usage factors are based on Reference 9 and on engineering judgment. Example data for Option 2 estimates are as follows:

OPERATING COST ESTIMATES FOR ONE FABRIC FILTER SYSTEM

Number of operating hours	800 h (1000 shifts)
Operating labor	2000 h/yr (2 h/shift)
Operating materials	$5000/yr (Vendor data)
Maintenance labor	1000 h/yr (1 h/shift)
Bag replacement (Total 1040 bags; 2-year bag life)	520 bags/yr x $30/bag = $15,600
Electricity consumption	1.235×10^6 kWh/yr
Natural gas	1000×10^3 ft^3/yr
Compressed air	4.8×10^6 ft^3/yr

The following assumptions were made in evaluating the system capital and annualized costs:

a) Because the I.D. fan regulates the operations of the multiple-hearth furnace (MHF), it is considered part of the incinerator system. Thus, it is not possible to have a common air pollution device serving more than one incinerator. Since the I.D. fan is an essential part of the MHF system and also generates the required pressure drop for the air pollution control device, the capital cost is divided between the MHF and air pollution control systems in proportion to the pressure drop.

b) The stack is considered an integral part of the MHF system; therefore, its cost is not considered part of the air pollution control equipment.

c) Because wet scrubbers are small compared with the size of the incinerator, they can be conveniently installed within the MHF building. Hence, no additional costs for insulation of the scrubber were considered in this option. Fabric filters and ESP's, however, are relatively large and must be installed outside the MHF building; therefore, the necessary insulation costs are included in the estimates.

d) Installation costs include no additional costs for site preparation or for facilities and buildings for any of the three air pollution control devices, as they are part of the MHF plant.

e) State and Federal taxes are not applicable to municipalities; hence, no provisions are made for taxes.

f) Because MHF are designed to be operated on a continuous basis, the basis for calculating operating costs is selected as 8000 h/yr of operation (a balance of 760 hours is allowed for downtime due to breakdowns, hot repairs, etc.). The MHF and the air pollution control equipment will be working around the clock 7 days per week.

g) The wastewater from the scrubber will be fed back to the primary water treatment system. Because the volume of this water is very small compared with the wastewater treated, no wastewater treatment costs are evaluated.

h) The dust recovered from the fabric filter and ESP will be mixed with the ash generated at the MHF and disposed of. Hence, there will be no additional handling costs for this dust.

i) The capital recovery factors used are based on a 10 percent interest rate and an average life of the air pollution control equipment for this type of service.

Table I presented the capital and annualized costs for all six options at plants with one, two, and eight incinerators. The cost data are based on each incinerator requiring its own captive air pollution control system, i.e., two identical systems at a plant having two incinerators, and eight identical systems at a plant having eight incinerators. Some cost savings will be realized when more than one identical system is installed. Capital cost evaluations also take this into consideration. Factors indicated by vendors are used in the cost calculations. The contingency costs are also adjusted to reflect the cost savings realized by installing several identical systems.

The following adjustment factors were used to arrive at the capital costs for plants with one, two, and eight incinerators:

	Number of incinerators at plant		
	1	2	8
Equipment cost factor (vendor data)	1	1.8	6.6
Contingencies	0.15	0.09/system	0.09/system
Performance tests	$6000/system	$6000/system	$6000/system

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